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Laser Performance Operations Model (LPOM): A Tool to Automate the Setup and Diagnosis of the National Ignition Facility

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Disclaimer

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A Tool to Automate the Setup and Diagnosis of the
National Ignition Facility

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ABSTRACT

The National Ignition Facility (NIF), currently under construction at the University of California's Lawrence Livermore National Laboratory (LLNL) is a stadium-sized facility containing a 192-beam, 1.8 MJ, 500-TW, 351-nm laser system together with a 10-m diameter target chamber with room for nearly 100 experimental diagnostics. When completed, NIF will be the world's largest laser experimental system, providing a national center to study inertial confinement fusion and the physics of matter at extreme energy densities and pressures. The first four beamlines (a quad) have recently been commissioned, and operations on the first bundle (units of eight beamlines) will begin in Summer 2005. A computational system, the Laser Performance Operations Model (LPOM) has been developed and deployed to automate the laser setup process, and accurately predict laser energetics. For each shot on NIF, the LPOM determines the characteristics of the injection laser system required to achieve the desired main laser output, provides parameter checking for equipment protection, determines the required diagnostic setup, and supplies post-shot data analysis and reporting.
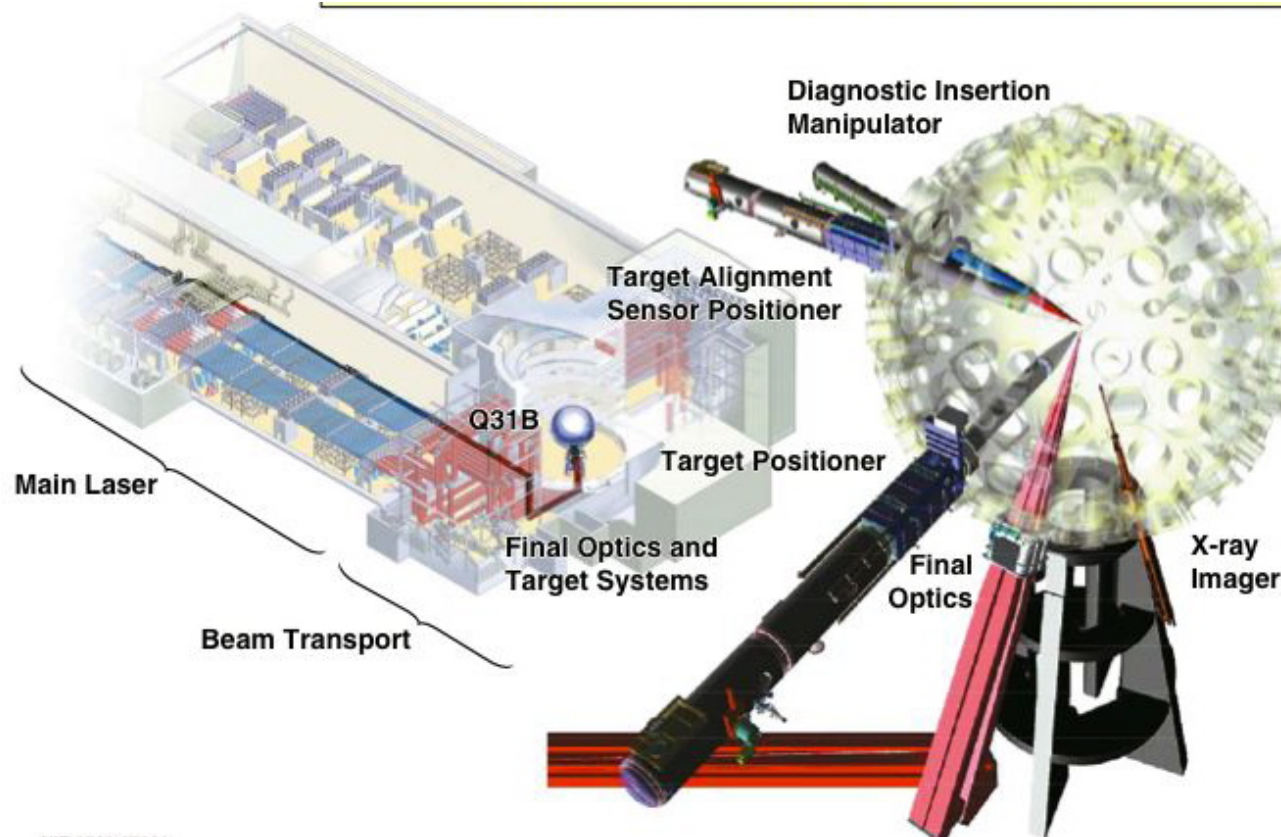
BACKGROUND SECTION

Description of the National Ignition Facility

- **NIF is a stadium-sized facility containing a 192-beam, 1.8-MJ, 500-TW, 351-nm laser system**
  - **The beams are grouped in 48, 4-beam quads, which share a common injection laser system**
- **The target is encased in a 10-meter diameter target chamber with room for nearly 100 experimental diagnostics**

NIF Operations Requires Detailed Laser Energetics Models

- NIF operations require precisely specified energy waveforms from 192 beams for a variety of pulse lengths and temporal shapes

- NIF laser pulses are amplified from 1 nJ up to 20 kJ
  - Injected pulses undergo significant pulse distortion due to gain saturation
  —

- The system must accurately control 192 beamlines and 48 injection laser systems that have variations in:
  - Beamline-to-beamline optical transmission;
  - Beamline-to-beamline amplifier slab configurations (gain);
  - Quad-to-quad amplifier pumping

- NIF to be operated at very high energy and power, but with low risk of optical damage

- The Laser Performance Operations Model (LPOM) has been developed to provide this functionality for NIF

FUNCTIONAL REQUIREMENTS

# Laser Performance Operations Model (LPOM) Functional Requirements

- **Automate shot setup**
    - Specifies injection laser energy and temporal shape;
    - Predicts laser fluence at all laser diagnostic locations;
    - Feedback data to update the laser model

- **Assists in equipment protection**
    - Assures that the predicted fluences and intensities lie within operational limits
    - Verifies that injection system is properly configured prior to main laser shot

- **Post-shot analysis and archive tool**
    - Post shot data reports and analysis tools
    - Web browser access to processed data provide easy access before, during and after shot operations

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LPOM supports shot planning, operations, shot director and NIF users

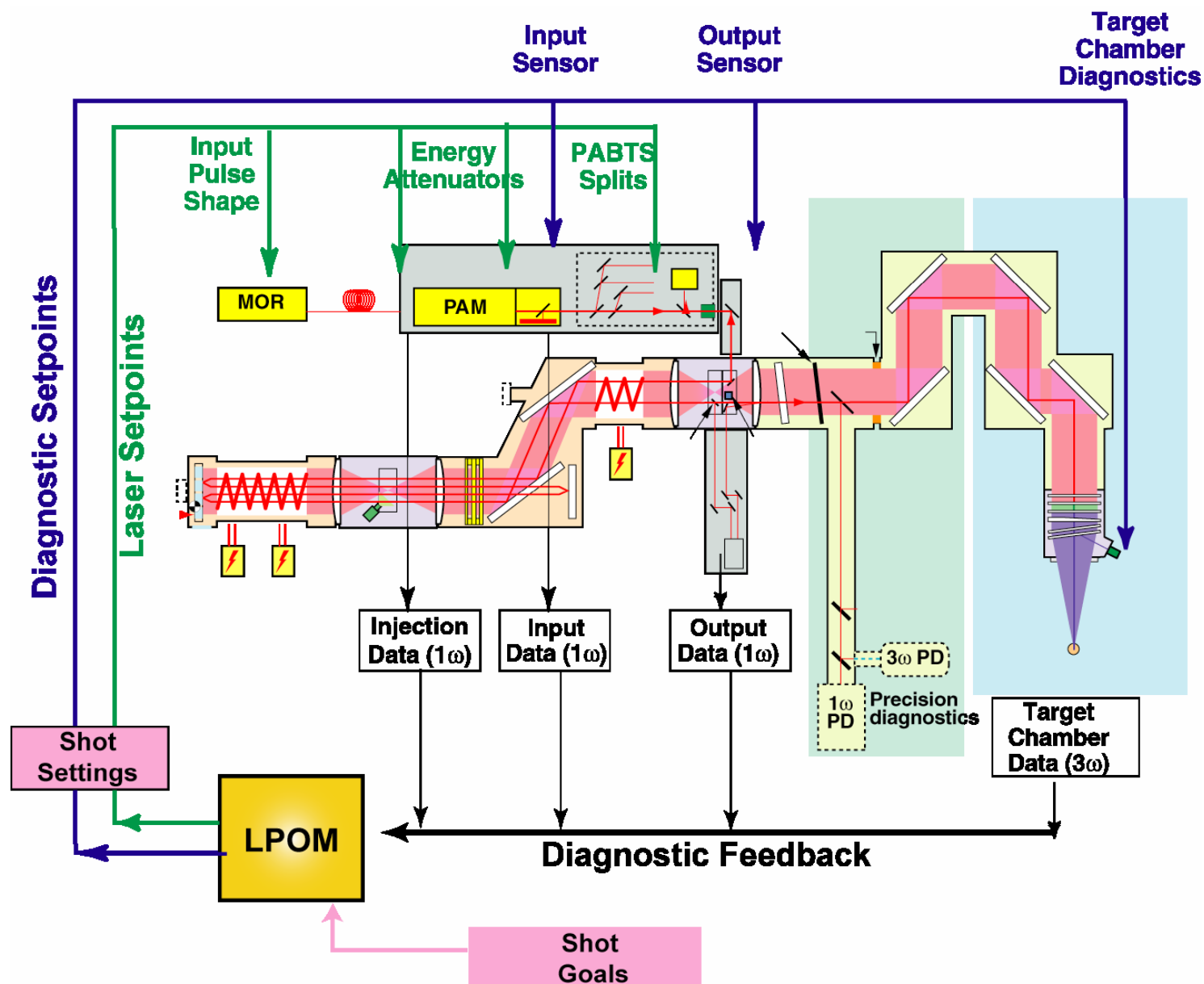# LPOM consists of several interacting, functional modules
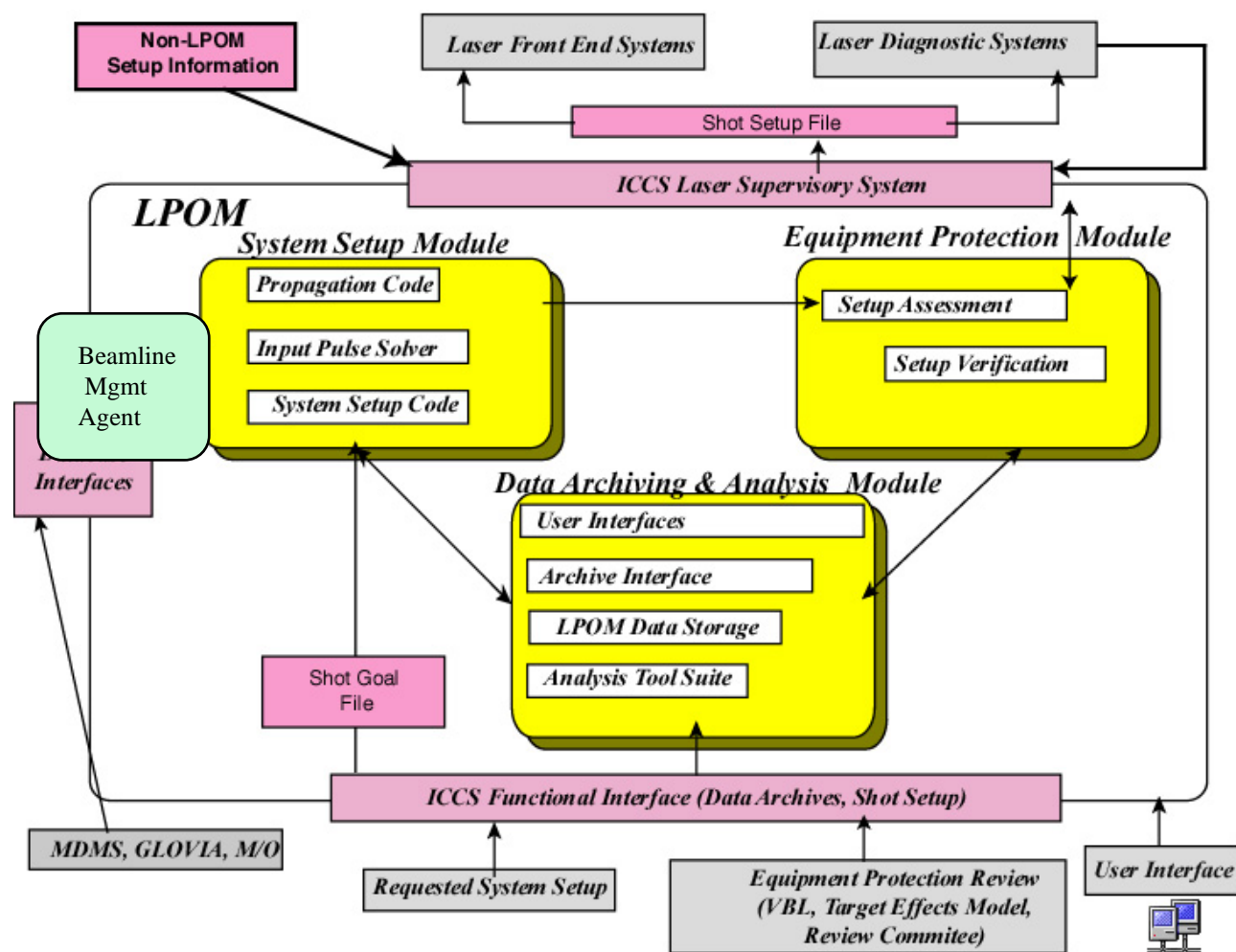
SHOT SETUP

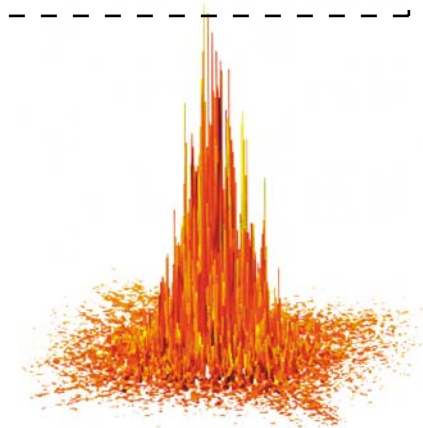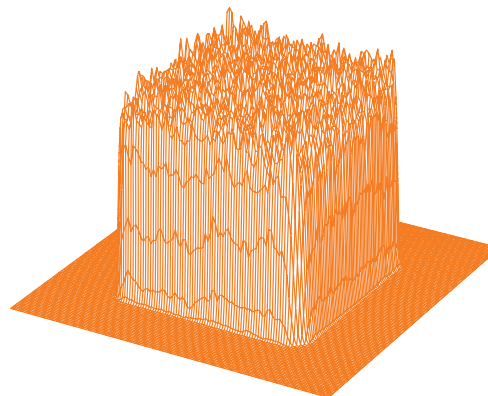# LPOM automates shot setup and uses post shot analysis to maintain an accurate model of NIF

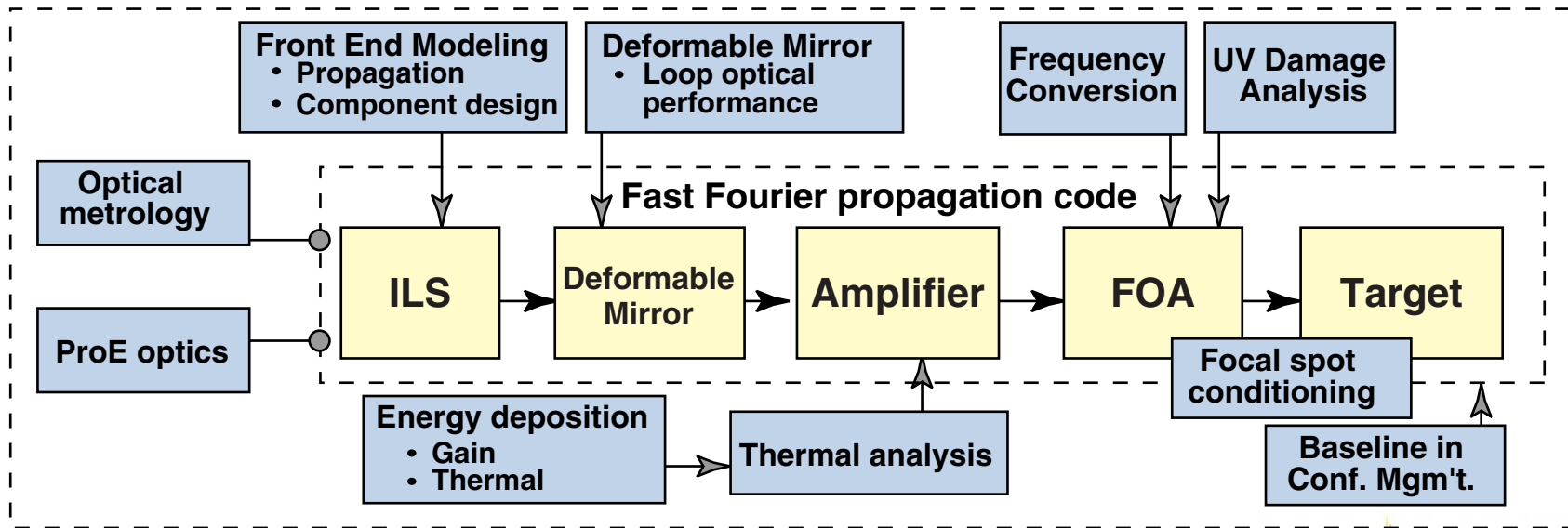# A comprehensive beamline model is essential to accurately describe how NIF works
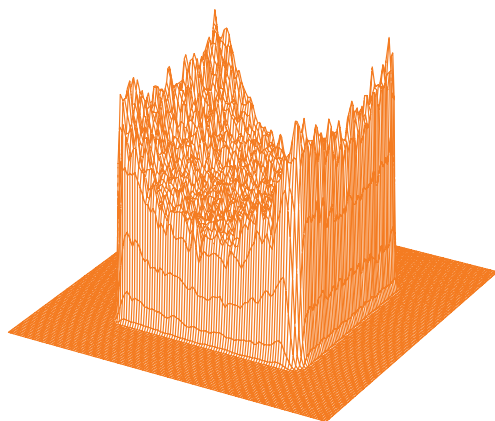
LPOM turns goals into the required shot settings for NIF subsystems

- **LPOM turns high level shot goals into specific shot settings**
- **Settings communicated to other NIF laser subsystems through**

EQUIPMENT PROTECTION

LPOM plays a critical role in the protection of the NIF laser

LPOM has three roles in the NIF equipment protection process

- **Prior to shot:**
  - **Compares predicted fluences and intensities to optical damage limits**

- **During the shot cycle:**
  - **Verifies injection laser system produces energy, power and spatial distribution required for a full system shot**
  - **Automatically alerts Shot Director with status of system**

- **After main laser shot:**
  - **Compares measured values to predicted, providing**
    - **A quick determination the success of a shot; and**
    - **Validation of the LPOM model**

LPOM provides expert groups detailed pre-shot analysis of equipment risk of proposed shots

- **Results of Shot Setup calculations provide information concerning the risk to critical optical component throughout the NIF system**
- **Due to level of confidence in LPOM calculations, no shots that exceed damage limits are allowed to be scheduled**

Q31B	Maximum	Optic Name	Beamline	Legend:	
✓ Optics Damage (Fluence)	99.34%	PM1	B318	✓	safe
✓ Delta-B	1.34%	Debris Shield	B318	⊘	above threshold
✓ Filamentation (Intensity)	29.46%	SF4	B316	⚠	above conditioning fluence

Optic Name	Max Flu	Ave Flu	Damage Flu	Damage Ratio	Max Delta-B	Beam Area	Tau Eq	Max Int	Filament Ratio	frac over damage	Loc
Debris Shield	15.86	6.26	4.00	3.97	1.34	781.84	2.27	3.59	0.18	0.98	B318
Tripler	14.85	5.85	4.00	3.71	0.54	853.11	2.27	3.35	0.17	0.97	B318
BSG	15.83	6.24	4.00	3.96	1.19	799.93	2.27	3.58	0.18	0.98	B318
FFL	14.84	5.85	4.00	3.71	1.05	853.11	2.27	3.35	0.17	0.97	B318
SHG	21.51	8.64	41.67	0.52	0.54	859.71	2.97	5.41	0.27	0.00	B318
Pol on refl	7.94	6.07	9.84	0.81	0.43	847.61	2.49	2.47	0.12	0.00	B315
Pol on refl	8.23	6.02	9.79	0.84	0.43	853.59	2.45	2.68	0.13	0.00	B316
Pol on refl	8.26	5.77	9.83	0.84	0.41	873.52	2.48	2.62	0.13	0.00	B317
Pol on refl	8.07	5.91	9.75	0.83	0.42	863.47	2.43	2.72	0.14	0.00	B318
LM3	7.85	6.07	9.83	0.80	0.43	847.70	2.49	2.45	0.12	0.00	B315
LM3	7.72	6.01	9.79	0.79	0.43	854.48	2.45	2.48	0.12	0.00	B316
LM3	8.08	5.76	9.82	0.82	0.41	873.81	2.48	2.57	0.13	0.00	B317
LM3	7.82	5.90	9.74	0.80	0.42	864.22	2.42	2.65	0.13	0.00	B318
LM2	0.11	0.06	8.94	0.01	0.00	911.76	1.89	0.05	0.00	0.00	B315
LM2	0.11	0.06	8.94	0.01	0.00	916.93	1.89	0.05	0.00	0.00	B316
LM2	0.12	0.07	8.94	0.01	0.00	941.53	1.90	0.05	0.00	0.00	B317
LM2	0.11	0.06	8.94	0.01	0.00	927.49	1.89	0.05	0.00	0.00	B318
Inject Mirror	0.17	0.06	21.72	0.01	0.00	2.48	1.84	0.08	0.00	0.00	B315
Inject Mirror	0.16	0.06	21.72	0.01	0.00	2.46	1.84	0.07	0.00	0.00	B316
Inject Mirror	0.25	0.09	21.72	0.01	0.00	2.46	1.84	0.12	0.01	0.00	B317
Inject Mirror	0.20	0.07	21.72	0.01	0.00	2.49	1.84	0.09	0.00	0.00	B318
PM7	20.74	8.64	22.88	0.91	0.32	859.83	2.59	5.19	0.26	0.00	B318
PM1	17.45	9.19	17.57	0.99	0.26	852.87	2.80	4.67	0.23	0.00	B318
TCVW	21.51	8.64	37.36	0.58	0.54	859.71	2.84	5.41	0.27	0.00	B318
SF1(pass4)	8.14	6.09	32.96	0.25	0.96	844.18	2.43	2.63	0.13	0.00	B315
SF1(pass4)	8.65	6.01	32.84	0.26	0.94	851.31	2.40	2.72	0.14	0.00	B316
SF1(pass4)	9.13	5.75	32.81	0.28	0.93	872.66	2.39	2.73	0.14	0.00	B317
SF1(pass4)	9.65	5.92	32.80	0.29	0.93	857.51	2.39	2.89	0.14	0.00	B318
SF3	12.11	9.39	37.80	0.32	1.04	848.54	2.93	3.37	0.17	0.00	B315
SF3	13.95	9.28	37.77	0.37	1.03	853.08	2.92	3.80	0.19	0.00	B316
SF3	13.39	8.87	37.46	0.36	0.99	873.36	2.86	3.52	0.18	0.00	B317
SF3	14.31	9.08	37.38	0.38	1.01	865.61	2.85	3.58	0.18	0.00	B318
SF4	17.54	9.39	38.43	0.46	0.20	846.19	3.05	5.45	0.27	0.00	B315
SF4	20.64	9.38	37.55	0.55	0.20	844.97	2.88	5.89	0.29	0.00	B316

LPOM verifies laser system is configured for main system shot

- **Prior to a full system shot, a shot using only the injection laser system is conducted**
- **LPOM determines if system is ready for full energy by comparing measurements to predictions**
  - **System readiness communicated to Shot Director within minutes of shot, along with recommended adjustments**

DATA ANALYSIS AND REPORTING

LPOM presents shot data in a drill down fashion

- **Web-based data reporting tool provides shot data, at various levels of complexity, to NIF community**
- **Drill-down navigated downward from Shot Status⇨Shot Metrics -> Detailed reports for each participating quad**
- **Parallel computational design assures scalability to full NIF**

System shot data reporting is accessible immediately to operations and users

- Second level is a detailed comparison of predicted and measured data
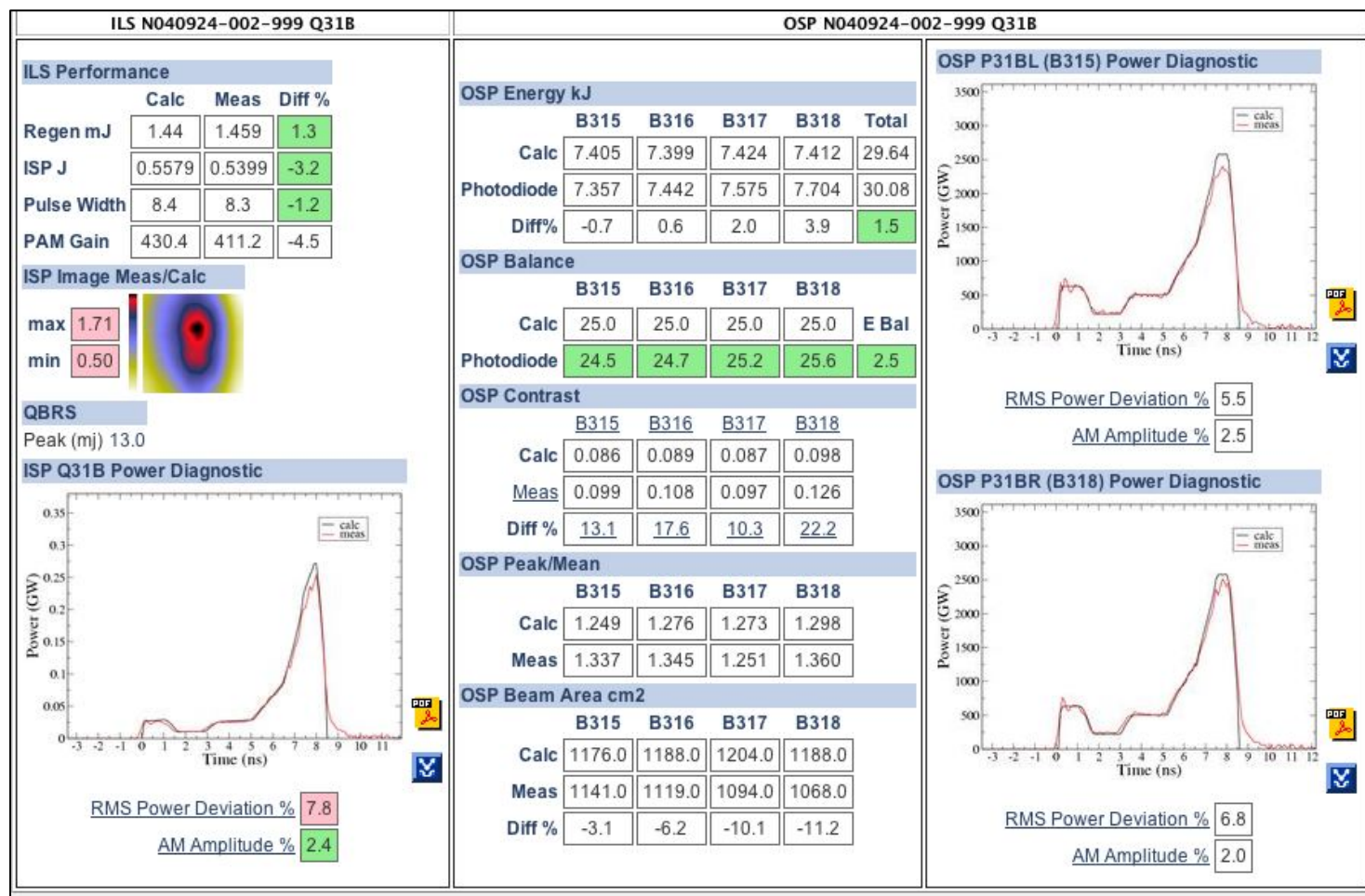
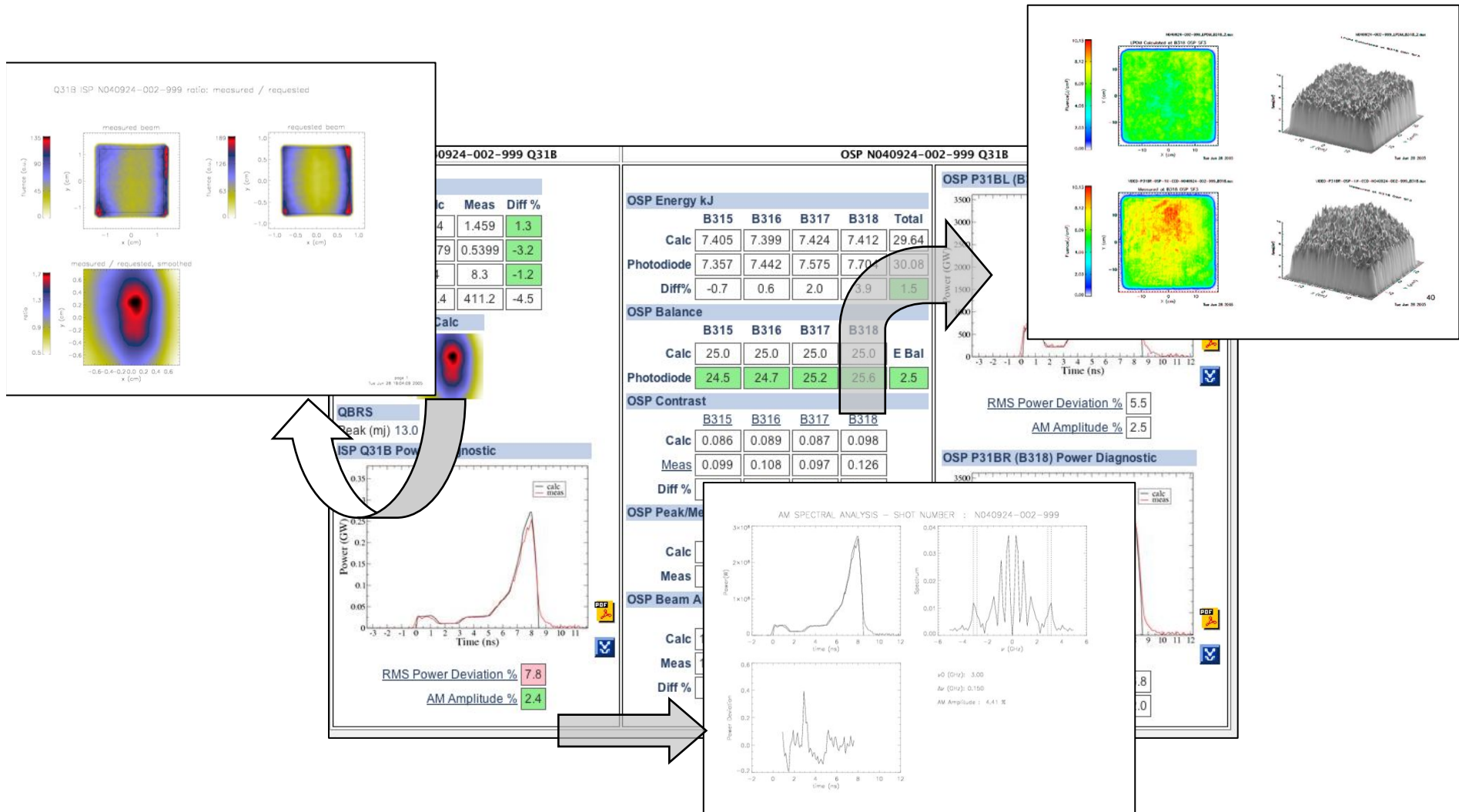# More detailed analysis results can be viewed from results page

- Hyperlinks from results page allow users to drill down to more detailed analysis reports
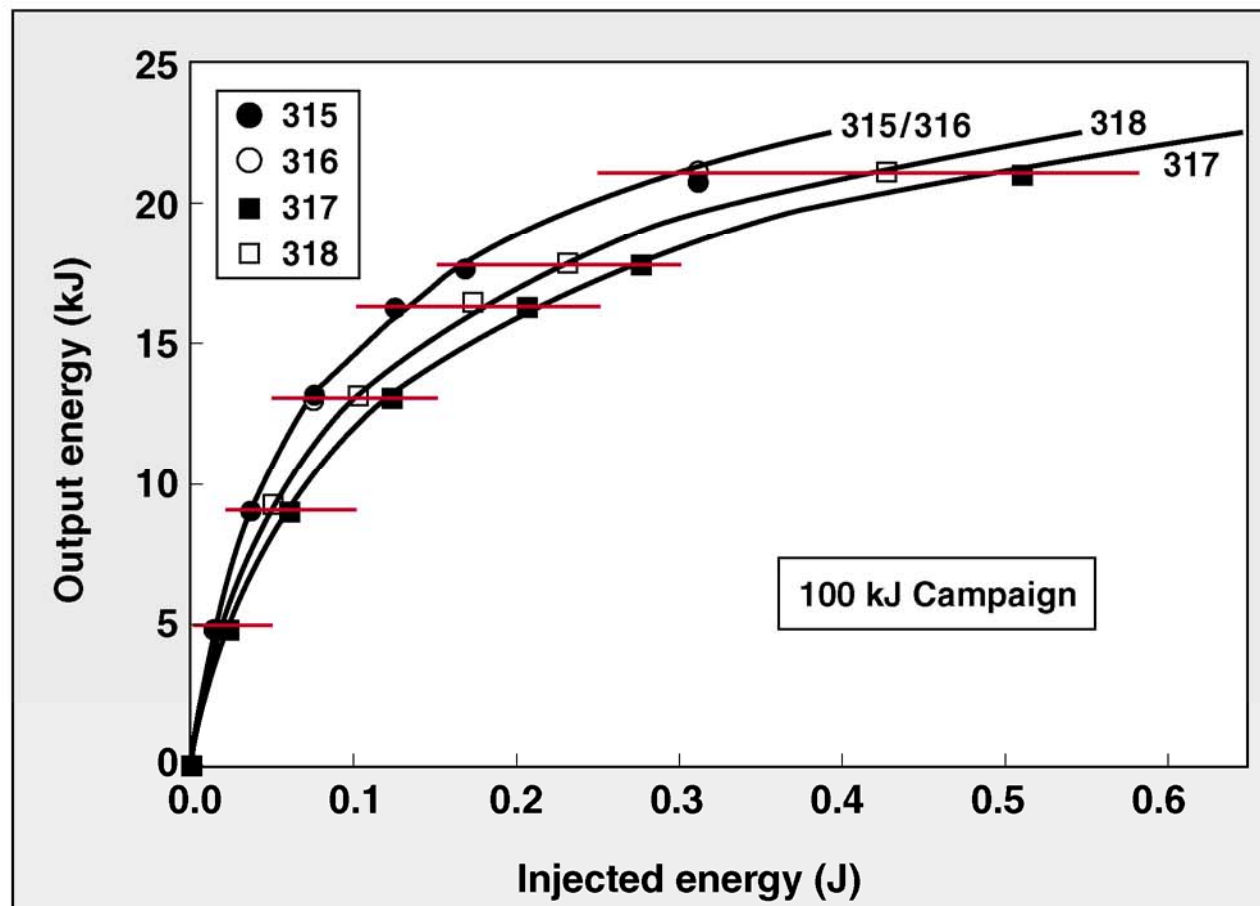- Processed predicted and measured data can be downloaded

RESULTS

LPOM has been able to accurately predict energies for each beamline for over a wide operating range

Bundle 31

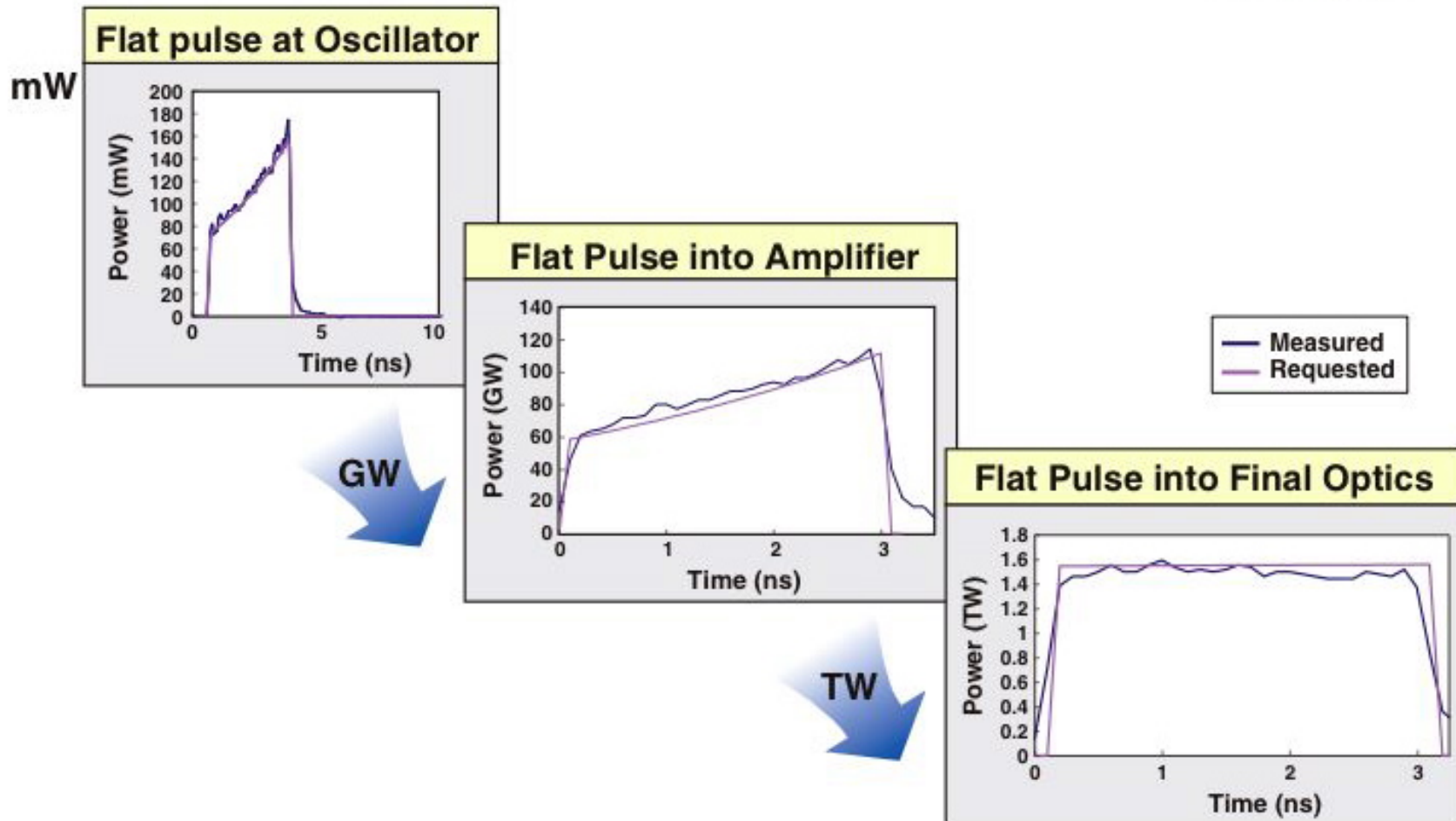| 311	312
313	314
315	316
317	318

- **LPOM calibrated with two low energy shots at beginning of campaign**
- **Energy balance (within quad) within 1-2% for all shots**

LPOM accurately models gain saturation of the laser temporal pulse as it propagates
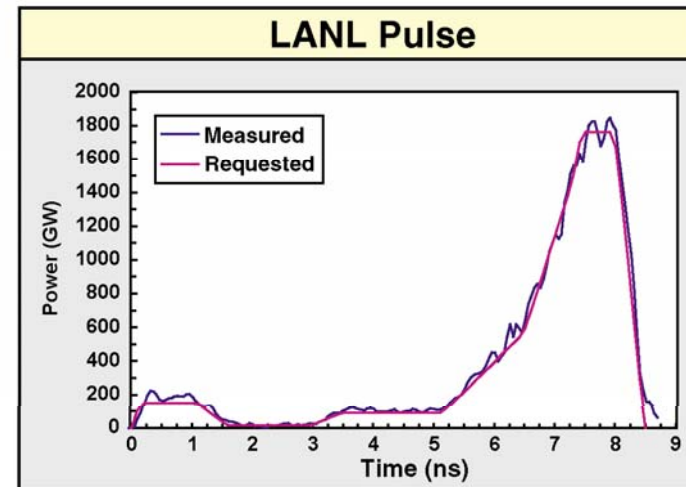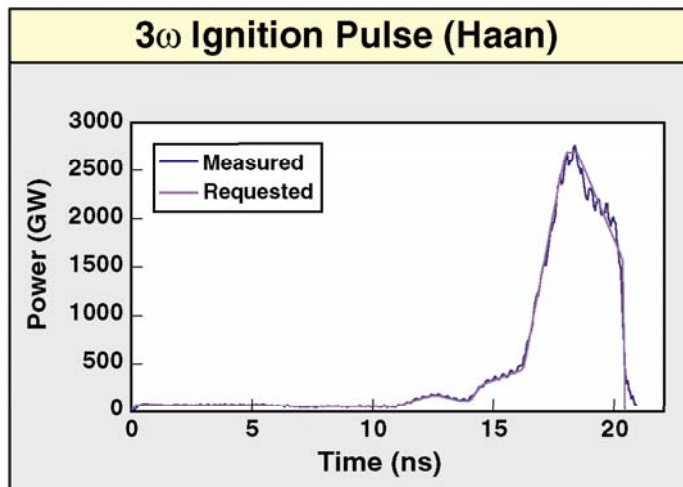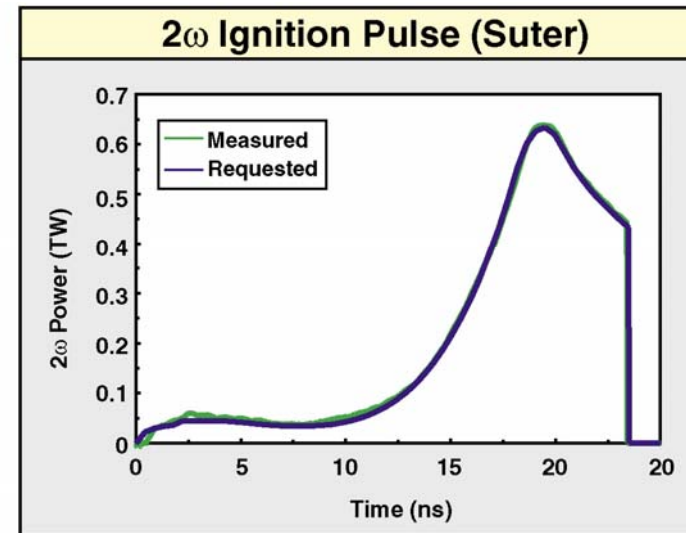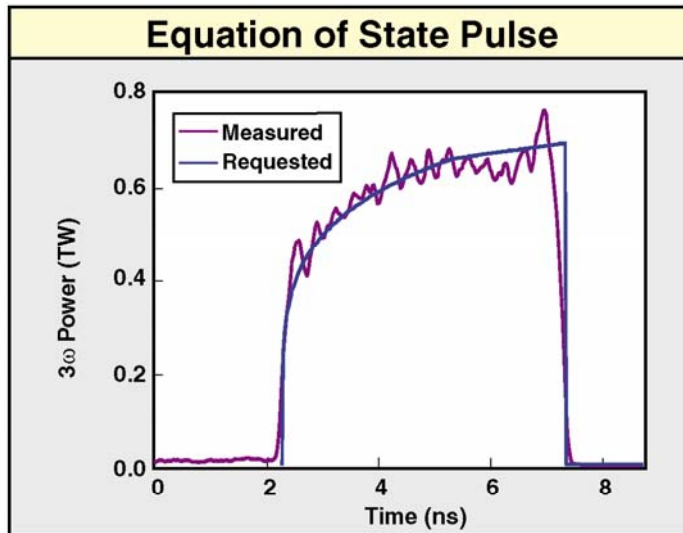

LPOM is the backbone of meeting target irradience requirements

LPOM has been able to accurately predict pulse shapes for a wide variety of missions

Equation of State Pulse

2ω Ignition Pulse (Suter)

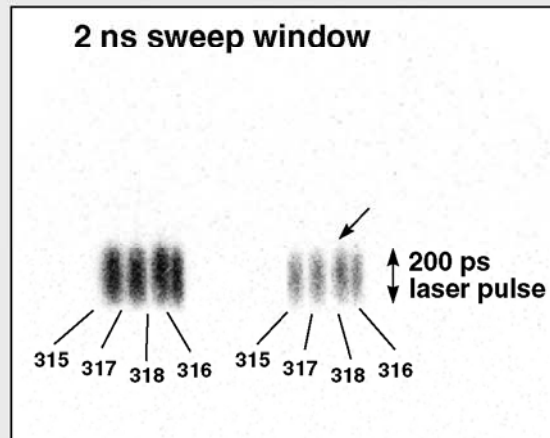**3ω Ignition Pulse (Haan)**

LANL Pulse

The observed RMS deviation of the Haan pulse is consistent with ignition requirements
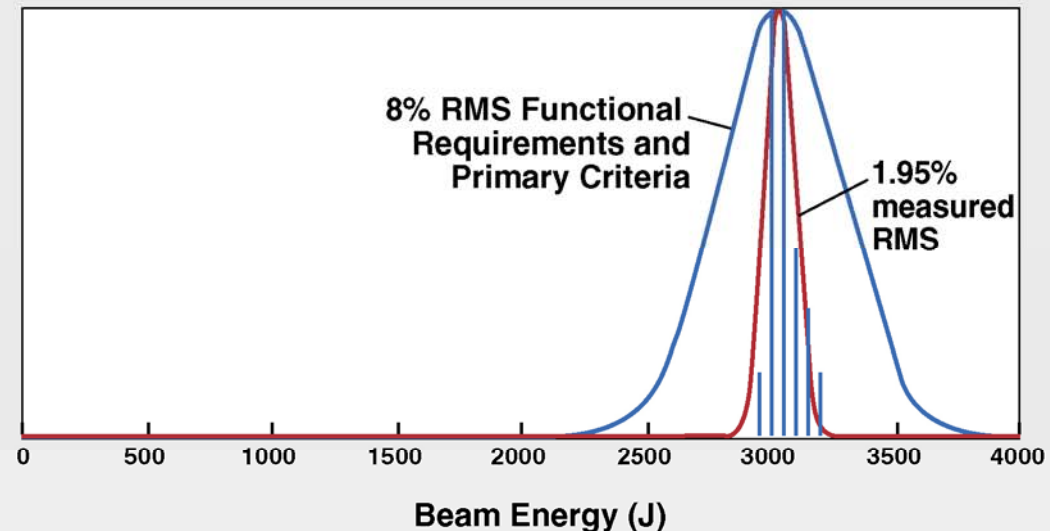
LPOM has helped NIF meet its functional requirements for energy accuracy

- Power balance requires an 8% RMS on 3w output energy
  — Target campaign shows < 2% RMS of energy on target

Beam Timing Adjusted to Within 6 ps (rms)

2 ns sweep window

200 ps laser pulse

315 317 318 316   315 317 318 316

Hydro Campaign Shot Energy Histogram

8% RMS Functional Requirements and Primary Criteria

1.95% measured RMS

Beam Energy (J)

0   500   1000   1500   2000   2500   3000   3500   4000

Measured timing and energy stability are consistent with ignition requirements

Summary

- **LPOM serves a role in automated shot setup, equipment protection and data analysis for NIF**

- **LPOM has been an invaluable tool in NIF laser commissioning activities**
  - **Accurately set up shot for several laser configurations, and over a wide energy range**
  - **Provide energy balance amongst the quad to within 1-2%**
  - **Produces output pulse shapes that are flat or match complicated requested shapes**

- **LPOM provides post-shot data reporting and analysis**
  - **Web-based reporting tool provides data to aid shot operations, shot planning and data analysis**

- **LPOM has been proven to be scalable and capable of operating in a fully automated fashion**